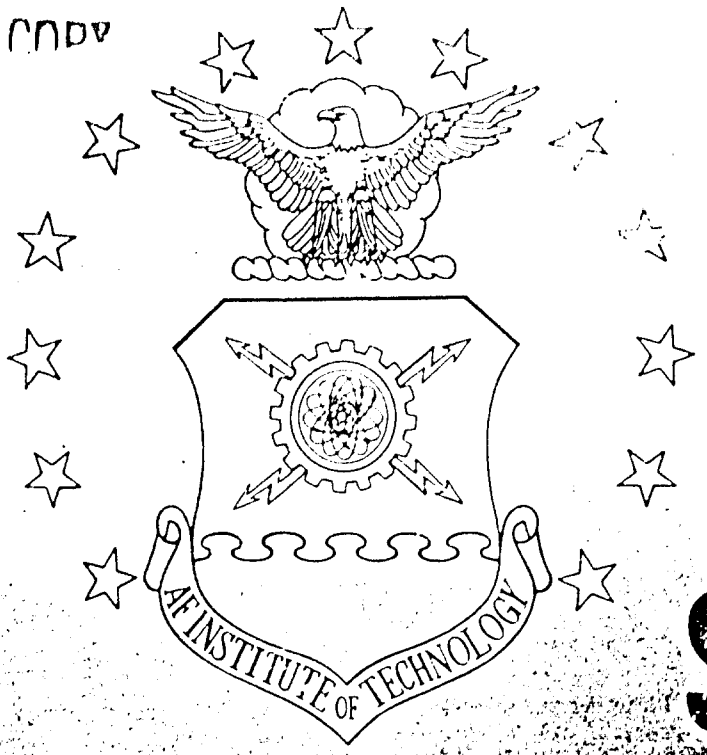

DEPARTMENT OF THE AIR FORCE

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R&M QUALITY TEAM CONCEPT AND C-17 DESIGN AT DOUGLAS AIRCRAFT COMPANY: AN R&M 2000 INITIATIVE CASE STUDY

THESIS

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THESIS

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Captain, USAF

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Tony Phillips

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Abstract

In response to U.S. Air Force emphasis on improving weapon system reliability and maintainability (R&M), Major James F. Guzzi of the Aeronautical Systems Division's C-17 System Program Office, located at Wright-Patterson Air Force Base, Ohio, developed a quality management initiative called the R&M Quality Team Concept. The purpose of the concept is to provide companies better management of R&M during the Full-Scale Engineering Development acquisition phase. Douglas Aircraft Company (DAC) agreed to implement the R&M Quality Team Concept during design of the C-17, the Air Force's next-generation transport aircraft.

This thesis examined the effect of the R&M Quality Team Concept as instituted by DAC on the quality management of the R&M process during C-17 design. Research assessed the concept's perceived impact on the following three areas: (1) communication on R&M issues; (2) R&M problem solving; and (3) specific C-17 design changes. Research instruments consisted of a survey administered to DAC employees and interviews with management at DAC's Long Beach, California facility. Hypothesis testing using z and t-tests assisted in evaluating survey results.

The results of this study revealed overall employee support for the R&M Quality Team Concept. The concept provided a method of R&M management and problem solving not available in a traditional program organization, and a number of C-17 design changes resulted from concept application. Studying the R&M Quality Team Concept's use in other program organizations and its function in managing R&M during the transition from Full-Scale Development to Production is recommended.

R&M QUALITY TEAM CONCEPT AND C-17 DESIGN AT DOUGLAS AIRCRAFT COMPANY: AN R&M 2000 INITIATIVE CASE STUDY

I. Introduction

General Issue

The United States Air Force acquires and operates a wide variety of weapon systems in order to execute national defense policy. As complexity and costs of these systems have risen in recent years, so has the necessity to reexamine methods of managing weapon systems' reliability and maintainability (R&M). Air Force leadership has focused on R&M as a means to improve combat effectiveness. General Earl T. O'Loughlin, former commander of Air Force Logistics Command, claimed R&M must be the "keynote" to all command activities. According to General O'Loughlin, potential defense budget shortfalls may require the Air Force to choose between purchasing new weapon systems without spare parts or purchasing fewer systems. General O'Loughlin further stated the following:

> The only way we can overcome difficulties, then, is through technology and reducing the mean time between failures. The reliability and maintainability issue becomes very important. It's your only way out -- build it right the first time and not have to repair it [19:9].

The Secretary and Chief of Staff of the Air Force also underscored R&M as essential in all acquisition programs (7:1).

In response to this R&M emphasis, Major James F. Guzzi of the Aeronautical Systems Division's C-17 System Program Office located at Wright-Patterson Air Force Base, Ohio, developed a quality management

initiative called the R&M Quality Team Concept. The purpose of the concept was to provide companies better system management of R&M during the Full-Scale Engineering Development acquisition phase. The concept was intended to serve as a means to "improve the effectiveness of a company's design organization to recognize and manage the R&M Program in day-to-day design activities" (22:1). This is accomplished by focusing management attention on the system-level R&M process, and enabling engineers and system designers to work as a team in solving system-level R&M problems under management's direction. Douglas Aircraft Company (DAC) agreed to implement the R&M Quality Team Concept during design of the C-17, the Air Force's next-generation transport aircraft. DAC is currently using the R&M Quality Team Concept to help meet R&M requirements specified in the C-17 contract (25:1). No evaluation of the R&M Quality Team Concept's effectiveness has been accomplished. The problem for research was to determine the impact of the R&M Quality Team Concept on DAC's C-17 R&M Program.

Research Objective

The objective of this research was to determine the effect of the R&M Quality Team Concept as instituted by DAC on the quality management of the R&M process during C-17 design.

Research Questions

1. How has the R&M Quality Team Concept affected communication on R&M issues between C-17 program organizations within DAC, and between those organizations and management?

2. How do DAC personnel perceive the R&M Quality Team Concept's impact on the C-17 R&M design process?

3. What contributions has the R&M Quality Team Concept made to R&M in C-17 design?

Scope of Research

As the first company to have applied the R&M Quality Team Concept, Douglas Aircraft Company was the subject of research. Specifically, the impact of the R&M Quality Team Concept as employed in design of the C-17 during the Full-Scale Engineering Development phase of the acquisition cycle was examined. This study focused on personnel responses to the R&M Quality Team Concept at DAC's Long Beach, California, facility where the C-17 is being designed, and examined several examples of how the concept impacted C-17 design.

This examination of the R&M Quality Team Concept as applied by DAC begins with a review of literature pertinent to the concept's development. A description of the methodology used in conducting research ensues, followed by a presentation of research results. Discussion of the results, conclusions drawn from the investigation, and recommendations for future research complete the study.

II. Literature Review

Introduction

This chapter reviews background information underlying development of the R&M Quality Team Concept. The first section defines R&M and discusses how effective management of R&M contributes to product quality. Next, the development of R&M 2000 will be addressed. Emphasis on R&M in the C-17 program will be reviewed. The R&M Quality Team Concept will then be described, followed by an examination of the management principles supporting the concept.

Reliability and Maintainability

Reliability is defined by Juran as the probability that a system will perform satisfactorily for a given time period under specified operating conditions (26:13-15). Blanchard stressed the four elements of probability, satisfactory performance, time, and specified operating conditions in fully defining system reliability (2:12). According to Blanchard, probability refers to a fraction or percent representing the number of an item's successful performances divided by the total number of trials. For example, if an item's "probability of survival" is 75%, the item should perform properly 75 out of 100 times it is used (2:13). Satisfactory performance includes a combination of qualitative and quantitative performance specifications which describe how a system should operate. Blanchard considered the element of time most important because it "represents a measure against which the degree of system performance can be related" (2:13). Air Force specifications often define reliability in terms of mean time between failure (MTBF)

or mean time between maintenance (MTBM). The final element in defining reliability, specified operating conditions, refers to environmental factors encountered during system operation or during transportation, handling, and storage of the system. These four elements combine to determine a system's reliability (2:13).

Distinct from reliability, yet also vitally important in Air Force acquisition, is a weapon system's maintainability. Maintainability pertains to the amount of resources required to keep an item in, or restore the item to, a specified condition (4:2). Maintainability may also be thought of as the relative ease and simplicity of repair. Good maintainability implies an item can be maintained with minimum investment of personnel, time, facilities, or other resources, without adversely affecting the item's mission (2:15).

The Air Force R&M Action Plan Development Team discovered a variety of definitions for reliability and maintainability combined as "R&M." The design engineering community generally defines R&M in terms of the previously mentioned measurable characteristics such as MTBF. According to statisticians, R&M are described by probability distributions of an item's lifetime. Management tends to view R&M in terms of "readiness, durability, and logistics support" (6:III-1). The Air Force defines R&M in terms of performance impacting combat capability. Under this definition, weapon systems with high R&M sustain operational performance over time and are "force effectiveness multipliers" by being capable of repeated enemy engagements (7:1).

Quality and R&M. To more fully understand the significance of R&M as inherent characteristics of a weapon system or any other manufactured product, one must consider how R&M relate to the concept of quality. Juran and Gryna define quality as "fitness for use" (27:1). This definition can be viewed from various perspectives. In Juran and Gryna's example, fitness for use to a manufacturer may mean a product's capability to be processed with high productivity and minimal downtime. From a merchant's perspective, fitness for use may refer to correct labeling and adequate packaging of a product. The ultimate user might judge the same product's fitness for use by how well the product does what it was purchased to do. Because a product can have different uses and perform varied functions, multiple attributes determine fitness for use. No single element can define product quality. Juran and Gryna refer to the elements that determine quality of a product as "parameters of fitness for use" (27:2). Parameters of fitness for use can be used to categorize a product's quality characteristics. Examples of such categories include quality of design, quality of conformance, and availability quality. Design quality is a product's "grade" as determined by how well the product satisfies a user's needs (26:1-2). Conformance quality is determined by whether a product meets the intent or specifications of the design (27:2). Availability quality refers to product performance in the future and is determined by two factors -- reliability and maintainability (34:516). R&M are subsets of a product's fitness for use and are essential quality elements. Therefore, improvements in R&M will contribute to improvements in overall product quality.

Because R&M are integral to product quality, R&M management during product design and production is crucial in enhancing product quality. General Alfred G. Hansen, commander of Air Force Logistics Command, claimed quality cannot be managed as an entity separate from reliability and maintainability. General Hansen also emphasized the need for "new mind-sets" built around preventing product defects in order to improve quality. According to General Hansen, "We must learn to think of quality as a cultural change that combines the right technology with the right people, and provides a team environment that will encourage everyone to work together" (30:1). Effective management of R&M is central to improved quality management.

R&M 2000

Military and industry program managers have traditionally given cost, schedule, and performance primary emphasis in the weapon system acquisition process. General Robert D. Russ, former Deputy Chief of Staff for Research, Development and Acquisition, stated the following concerning the status of R&M during acquisition:

> The desirability of reliable and maintainable systems has long been recognized, but pursuit of such reliability has been erratic. Life-cycle costs, which are strongly driven by R&M, have often assumed a secondary role in the effort to produce system performance with budgeted front-end costs. Given the options to pay *now* or pay later, the choice was almost always later [42:122].

One reason offered for the "secondary role" given to R&M was failure to fully comprehend the impact of unreliable systems on budgets and combat capability (39:13). From a budgetary perspective, inadequate R&M require additional and more highly skilled manpower to keep a system in operation. More spare parts are required to compensate for R&M

deficiencies which, in turn, increase system life-cycle costs (42:122-123). Even more crucial from a military perspective is the adverse impact of neglected R&M on combat capability. Reliability has been recognized as the single most significant limiting factor in accomplishing wartime taskings (39:14).

In response to the need for increased emphasis on R&M in the weapon system acquisition process, the Secretary and Chief of Staff of the Air Force issued a 1984 memorandum which "renewed the Air Force commitment to R&M and committed the Air Force to demanding accelerated improvements in R&M in both new and fielded weapon systems" (6:I-1). Members of the Air Staff formed an R&M Action Plan Development Team composed of logistics, operations, and acquisition experts for generating recommendations to "institutionalize" R&M commitment (6:I-1). Goodman, as quoted by Meyer and Stott, defines something as institutionalized when it continues over time and is recognized as a fact by a majority of individuals in an organization (35:45-46).

The R&M Action Plan Development Team's recommendations resulted in compilation and approval of the Air Force R&M 2000 Action Plan. According to Brigadier General Frank S. Goodell, Special Assistant for Reliability and Maintainability, HQ USAF/LE-RD, the plan concentrates on management of R&M rather than technical aspects of acquisition (20:10). Management objectives emphasized in the R&M 2000 Action Plan include: establishing direction for achieving R&M improvement through clearly stated goals; establishing a communication program to support R&M commitment; and ensuring contractors have the capability to support R&M requirements (5:i).

In October 1987, the Office of the Special Assistant for Reliability and Maintainability issued a booklet entitled USAF R&M 2000 Process. The purpose of the publication is to describe "how to increase combat capability through good R&M practices," and continue the emphasis on R&M generated by the R&M 2000 Action Plan (7:ii). USAF R&M 2000 Process presents methods for bolstering management commitment to improved R&M through a "process" composed of the following three portions: (1) goals defining the purpose of the Air Force R&M Program, (2) principles providing a "framework for the many actions and players in the process," and (3) building blocks describing specific actions to advance the Air Force R&M Program (7:2).

R&M 2000 Goals. The fundamental purpose of the Air Force R&M Program is stated through five goals presented in USAF R&M 2000 Process:

1. Increase combat capability,
2. Increase survivability of the combat support structure,
3. Decrease mobility requirements per unit,
4. Decrease manpower requirements per unit of output, and
5. Decrease costs [7:2].

R&M's link to combat capability is based on the definition of reliability -- sustaining operational performance over time. Maintainability also impacts combat capability by dictating where and how often maintenance will be necessary. The combat support structure can be made more survivable by eliminating or reducing intermediate maintenance requirements. Reducing the combat support structure also yields the added benefit of decreasing the amount of transportation assets needed to mobilize a unit. Savings achievable by reducing manpower requirements to support a system can be used to strengthen the

force structure in other areas. Finally, R&M improvements can save money by reducing "procurement, manpower, or operating and support (O&S) costs" (7:4-7).

R&M 2000 Principles and Building Blocks. USAF R&M 2000 Process also outlines five principles which provide guidance and direction for institutionalizing R&M:

1. Management involvement,
2. Motivation,
3. Requirements,
4. Design and growth, and
5. Preservation [7:10].

As identified in the R&M Action Plan Development Team's Final Report, top-level management commitment is vital to an effective R&M program (6:III-1). USAF R&M 2000 Process identifies management involvement as the preeminent principle of R&M achievement (7:10). Motivation results from providing industry with the incentives necessary to improve R&M. In addition, R&M requirements must be clearly communicated to industry in "operational terms." Design and growth relate to engineering R&M into a system from the beginning and continuing to promote R&M throughout system development. Lastly, system R&M must be preserved during production and operation in order to achieve the benefits of improved, "designed-in" R&M (7:10). R&M 2000 Principles "are universally applicable to all programs" (7:9)

USAF R&M 2000 Process further states Building Blocks are techniques which have been used successfully to promote R&M in system acquisition programs. Incentives and warranties are examples of R&M 2000 Building Blocks used to motivate industry to meet or exceed R&M specifications during system development. Another example is

integrating R&M efficiencies into system design during the Systems Engineering Process (7:26,58). The goals of R&M 2000 "can be achieved by committed application of the R&M 2000 Building Blocks within the framework of the R&M 2000 Principles" (7:2).

R&M and the C-17

During C-17 development, R&M are receiving significant emphasis, with the objective being eventual operation of the most reliable and maintainable transport aircraft in the Military Airlift Command's inventory (41:7). The C-17 program has been referred to as "perhaps the first major weapon program to elevate R&M to near-parity with mission capability" (43:55). One reason for the R&M emphasis is the envisioned nature of C-17 missions. The C-17 is designed to carry both conventional and outsize cargo from bases in the U.S. to austere airfields around the world, combining both strategic and tactical airlift roles. Consequently, C-17 destinations may not have adequate MAC support. According to Lieutenant Colonel Rolf E. Forseth, Chief of Logistics Management for the C-17, as quoted in Aviation Week & Space Technology,

> Reliability is critical because an aircraft may be away from home station for significant periods of time. We have a worldwide arena that we work in, and we must be worldwide-capable. We want to reduce any logistics requirements and, of course, reliability reduces those requirements [45:61].

A second reason for R&M emphasis during C-17 development is the resultant reduction in life-cycle costs. C-17 R&M requirements are substantially improved compared to current MAC aircraft. As a result, the C-17's long-term operating costs for the amount of cargo carried are projected to be lower than similar costs for strategic transports

in the present fleet. For example, the annual operating and support (O&S) cost for each C-141 and C-5B is $6 million and $12.1 million respectively. The projected O&S cost for the C-17 is $7.5 million per aircraft, and the C-17 can carry twice as much cargo as the C-141. In addition, the forecast cost per flying hour for the C-17 is approximately the same as for the C-141 and less than half the costs per flying hour for the C-5A and C-5B (36:26). Maintenance man-hours per flying hour for the C-17 are guaranteed by contract to a level of 18.6; current MAC aircraft range from 25 to 60 (45:61).

Although the C-17 contract was written before the implementation of R&M 2000, provisions of the contract are "essentially in line with the main concepts of R&M 2000" (45:61). Included in the contract is a warranty program under which DAC guarantees the C-17 will meet or outperform 20 R&M measurements. The contract states if the prescribed performance goals are not met, DAC must absorb the costs of achieving those goals. According to the director of C-17 program development at DAC as quoted in the Military Logistics Forum, "This is the most demanding warranty that's ever been part of a DOD contract" (43:55). Also, a $12 million incentive award is available to DAC if the C-17 meets prescribed performance goals during an operational readiness review beginning 30 days after delivery of the 12th aircraft. The C-17 warranty and incentive programs provide clear motivation for DAC to achieve contracted R&M specifications.

All participants in C-17 acquisition and operation benefit if the C-17 achieves prescribed R&M specifications. The Air Force and Department of Defense gain a combat-ready weapon system which will

improve the nation's airlift capability. Moreover, the lifetime costs of the system will be substantially lower than those of any transport now available. From the contractors's perspective, R&M requirements must be met or the warranty requires achievement of the measures at contractor expense. In addition, a monetary incentive is available if specified standards are realized. One method employed by DAC intended to improve C-17 R&M is the R&M Quality Team Concept.

The R&M Quality Team Concept

The R&M Quality Team Concept is a quality project management initiative aimed at promoting R&M during weapon system acquisition. This R&M 2000 initiative was developed by Major James F. Guzzi, R&M Manager for the C-17 Program Office. The purpose of the R&M Quality Team Concept according to Major Guzzi is to "improve the effectiveness of a company's design organization and manage the R&M Program in day-to-day design activities" (22:1).

Because they are inherent characteristics of system design, R&M must be addressed from the beginning of an acquisition program (2:13,15). R&M are designed into a system, and designing modern weapon systems is an exceptionally complex task. The complexity of the design process presents a formidable challenge to aerospace industry managers attempting to comply with stringent R&M requirements. In constructing the R&M Quality Team Concept, Major Guzzi made the following assumptions about R&M and their relation to the design process:

1. R&M are co-equal in importance to cost and schedule and other performance factors.
2. R&M are total system design processes that effect the entire organization.

3. The management of R&M cannot be placed in any one function to be responsible for the "total process."
4. It is the responsibility of the organization to "manage" the system approach to R&M through the integration of all functions [22:2].

Major Guzzi developed the R&M Quality Team Concept as a method to institute a quality management approach to assist managers in solving R&M problems during design (22:2).

Underpinning the R&M Quality Team Concept is total management commitment. Structure of the concept is instituted by a charter from top-level management of the company responsible for system design. The charter establishes an R&M Review Council consisting of "second-tier management whose functional organizations are responsible for some part of the R&M program or related activity and who have decision authority" (22:6). Examples of Review Council members include the chief design engineer, chief of systems engineering, and lead reliability engineer. The Review Council identifies and prioritizes R&M problems in meeting system specifications. The Review Council then designates a Quality Team to further investigate top-level system problems and recommend possible solutions. Teams are established on an ad hoc basis and are composed of individuals from the functional areas affected by a particular problem. During the problem solving process, teams report to the Review Council; after problems are resolved the team members return to their positions in the organization (22:6-7). A model of the R&M Quality Team Concept is provided at Figure 1.

DAC was the first company to establish the R&M Quality Team Concept as part of its company standard practice in development of the C-17. Other companies and professional organizations, both within and

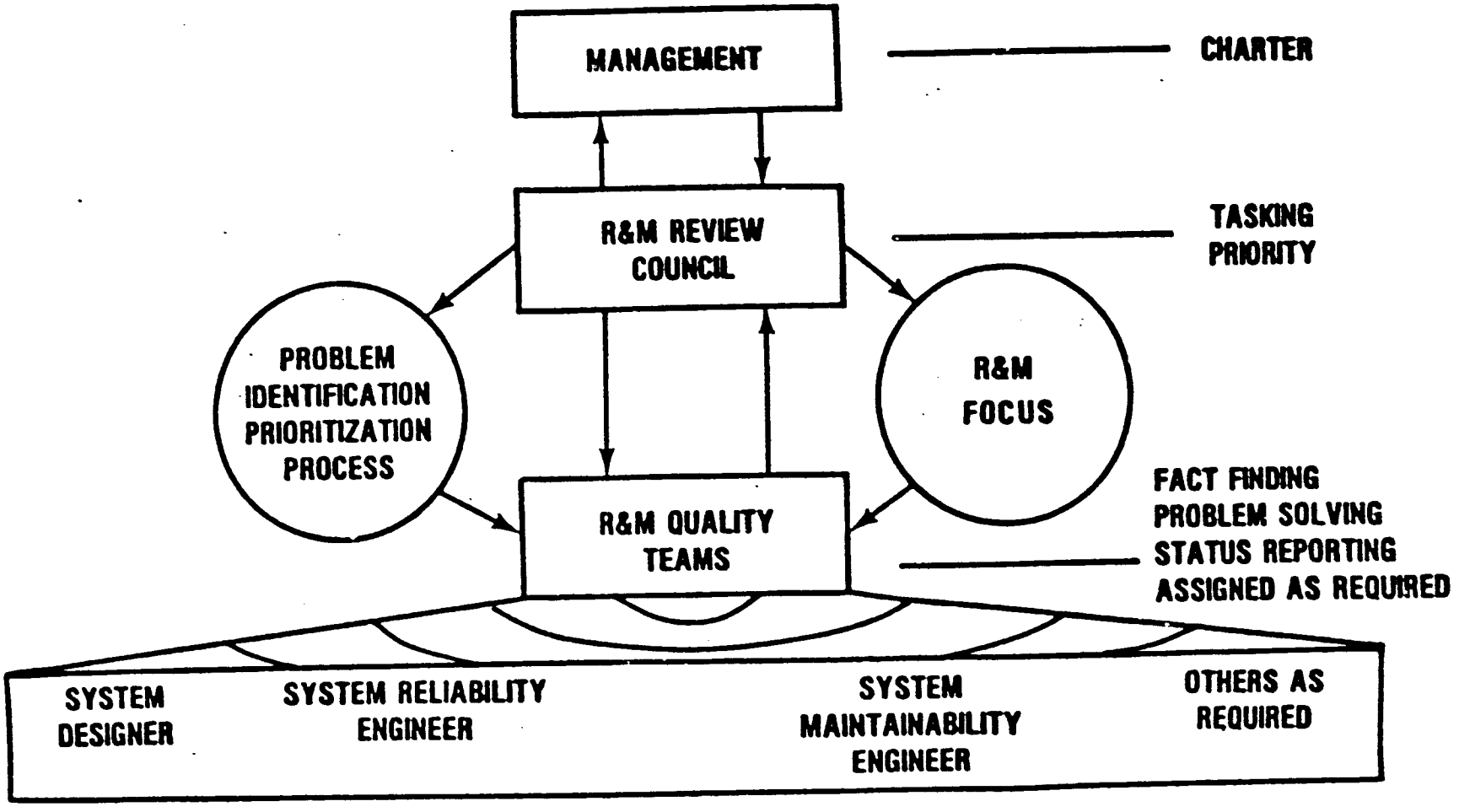

Figure 1. R&M Quality Team Concept Model (22)

outside the aerospace community, have also expressed interest in the concept and have taken steps toward concept implementation. Major Guzzi has presented the R&M Quality Team Concept by way of personal briefing to a variety of organizations and management levels, as shown in Table 1. According to Major Guzzi, the concept is widely applicable because of its foundation in management theory. He claims, "The principles of organizational and scientific theory that support the R&M Quality Team Concept have been researched and integrated into the concept to achieve R&M 2000 objectives" (22:3). The following section describes management principles applicable to the concept.

R&M Quality Team Concept and Management Theory

To better understand the R&M Quality Team Concept's role as a method to improve quality management of an R&M program, it is useful to review applicable management and organization theory. This section discusses how the concept relates to classical management functions and participative decision making.

Management Functions. According to Steers, et al., a generally accepted definition of management is "the process of planning, organizing, directing, and controlling the activities of employees in combination with other organizational resources to accomplish stated organizational objectives" (46:29). Management coordinates and directs the components of an organization to accomplish goals. Management also defines strategy and determines if an organization is effective in accomplishing its goals. Organization design, interdepartmental coordination, and problem solving are all activities performed by management (3:12).

Table 1. R&M Quality Team Concept Briefing Recipients (21)

Company	Representatives/Level	Date
Douglas Aircraft Company Long Beach, CA	C-17 Program/Vice President, Directors, Managers	September 85
Aerospace Industries Association San Francisco, CA	Technical Council	April 87
General Dynamics Corporation Fort Worth, TX	All Programs/Directors, Senior Managers	April 87
McDonnell Douglas Corporation St Louis, MO	MCAIR, Electronics, Astronautics/Directors, Senior Managers	June 87
Northrop Corporation Century City, CA	All Companies/Senior Executives, Vice Presidents, Directors, Managers	January 88
Olin Corporation Stamford, CT	President, Vice Presidents, Directors	March 88
Pratt-Whitney Corporation Hartford, CT	All Programs/Directors, Managers	March 88
Boeing Aerospace Company Settle, WA	All Programs/Vice President, Directors, Managers	May 88
Lockheed Corporation Burbank, CA	All Companies/Vice Presidents, Directors, Senior Managers	June 88
Hughes Radar Group El Segundo, CA	Radar Group/Vice President, Directors, Managers	June 88
Rockwell Corporation Los Angeles, CA	All Programs/Directors, Managers	June 88
Boeing Military Aircraft Company Wichita, KS	All Programs/Vice President, Directors, Managers	July 88
Martin-Marietta Corporation Denver, CO	All Programs/Vice President, Directors, Managers	July 88

The R&M Quality Team Concept proposes to improve management of R&M programs during weapon system design (22:1). Execution of the classic management functions of planning, organizing, directing, and controlling is conducted by the R&M Review Council. The council plans by identifying and prioritizing actual or potential problems in achieving R&M goals. Organizing and directing functions are accomplished by the council's selection of an R&M Quality Team to examine a specific problem area. The Review Council then controls the process by having Quality Teams report directly to the council until problems are resolved (22:6).

Participative Decision Making. Participative decision making (PDM) refers to a process through which "individuals and groups are included in the decision-making processes which affect them" (32:18). Lowin describes PDM as a method of operations in which decisions are arrived at by those persons who will execute the decisions (31:69). Turney and Cohen, as quoted by Minchello, define PDM in a relative sense, where managers vary participation "according to immediate task requirements, participant characteristics, situational conditions, and likely task outcomes" (37:19-20). According to Lyu and Roffey, evidence suggests PDM is most effective when goals are specific and verifiable as opposed to vague and general (32:22). Moore and Stevens cite potential benefits of PDM as improved job satisfaction and task performance, greater worker commitment, and increased worker acceptance of goals, decisions, and problem solutions (38:29).

PDM is incorporated into the R&M Quality Team Concept. The organizational goals are enhancing R&M by solving R&M problems.

Members of the R&M Review Council participate in decision making by identifying and prioritizing problems and selecting solutions from R&M Quality Team recommendations. Quality Team members combine expertise from their respective functional areas in developing solutions for recommendation to the Review Council. The Review Council can tailor the composition of the Quality Team to the requirements of a specific problem. The R&M Quality Team Concept uses PDM principles to address R&M at the system level, broadening management's ability to draw upon talent from more than one area of the organization to solve R&M problems (22:4).

By tying management functions to improving R&M and incorporating PDM into R&M problem solving, the R&M Quality Team Concept can be viewed as an attempt to institutionalize commitment to R&M within an organization. The following chapters describe the methodology, results, and conclusions drawn from the research examining the concept's effectiveness as a management initiative.

III. Methodology

Introduction

The methods employed to assess the R&M Quality Team Concept's impact on management of C-17 R&M at DAC consisted of a survey administered to all DAC personnel involved with the concept, and personal interviews in the field with DAC management. Surveys were distributed and interviews conducted from 21 to 25 March 1988. This chapter describes the research measures used, analysis performed, and possible limitations of the research.

Research Measures

A survey was developed for evaluating the attitudes of DAC workers and management toward various aspects of the R&M Quality Team Concept (Appendix A). The first four survey items revealed to what extent individuals were involved with R&M Quality Teams. The remaining survey questions (with the exception of question 9) were constructed in "semantic differential" format (17:246). To establish content validity, the survey was evaluated by Major Guzzi, originator of the R&M Quality Team Concept. The survey was also reviewed by members of AFIT's Department of Communication and Organizational Sciences.

In addition to the survey, field research was conducted at DAC's Long Beach, California, facility where the C-17 is under development. A weekly R&M Review Council meeting was observed, and interviews with DAC management involved in the R&M Quality Team Concept were conducted. Answers to survey questions were based on subjective impressions from DAC personnel. Consequently, personal interviews were conducted in an

effort to substantiate these impressions by further addressing the investigative questions and identifying specific examples of how the R&M Quality Team Concept had impacted organizational communication and problem solving with respect to R&M issues. Structure of the interviews was based on the questions posed in the written survey. However, personal interviews permitted a more in-depth examination of managerial attitudes toward the concept than was possible by using the survey exclusively.

Approval to administer the surveys and conduct interviews was obtained from Mr Shel Hess, Chief of DAC Systems Engineering. The survey was distributed to all DAC employees having any involvement with the R&M Quality Team Concept. This included approximately 100 engineers and other individuals involved in the design process who had been members of R&M Quality Teams. Managers interviewed included current and former members of the R&M Review Council. A total of 110 surveys were distributed to DAC employees. The following sections describe attributes of each of the survey measures as they support the three research questions stated in Chapter I.

Research Question 1: Communication. Survey questions 5 and 6 addressed the R&M Quality Team Concept's impact on communication concerning R&M issues between program organizations (horizontal communication), and the adequacy of communication between the R&M Review Council and the R&M Quality Teams (vertical communication). To assess horizontal communication, subjects were asked to respond on a 5-point scale (ranging from "detrimental effect" to "positive effect," with a median anchor of "no effect") to the following question:

> How has the Quality Team process affected communication on R&M issues between C-17 program organizations (e.g., design, system and logistics support engineering, and functional departments within each organization)?

Subjects were also instructed to indicate on a 5-point scale (ranging from "poor communication" to "excellent communication," with a median anchor of "adequate communication") their opinion on the following question pertaining to vertical communication:

> How would you evaluate communication between the R&M Review Council and R&M Quality Teams (e.g., R&M Review Council's communication of objectives to R&M Quality Teams, receptivity of R&M Review Council to R&M Quality Team recommendations)?

Research Question 2: Impact on the R&M Design Process. Two survey questions were used to evaluate the R&M Quality Team Concept's impact on the C-17 R&M design process. Subjects were asked to respond on a 5-point scale (from "not valuable" to "extremely valuable," with a median anchor of "somewhat valuable") to the following two questions:

> How valuable has the R&M Quality Team process been in solving C-17 design reliability and maintainability problems?
>
> What is your overall opinion of the R&M Quality Team Concept as it has been applied to C-17 design?

Research Question 3: Examples Of Accomplishments. The final survey question was open-ended, asking subjects to list examples of C-17 design changes directly resulting from the R&M Quality Team process. The question also asked respondents to specify the changes' impact on reliability and maintainability. The purpose of this question was to identify contributions the R&M Quality Team Concept made to R&M in C-17 design in order to answer research question 3.

Analysis

If the R&M Quality Team Concept positively impacted management of R&M at DAC, the survey and interview results should have indicated the following: (1) improved organizational communication, (2) positive impact of the concept in solving R&M problems, and (3) specific examples of contributions to improved R&M made by R&M Quality Teams. Scaled survey results were manually compiled and presented in a descriptive format, and hypothesis testing on the results was conducted. Written survey comments were collected and presented in a narrative format. Consistencies or inconsistencies between the survey results and the interviews were highlighted.

Hypothesis Testing. For part of the survey data analysis, parametric analysis was used to examine scaled survey responses. In Foundations of Behavioral Research, Kerlinger stated the best procedure in analyzing ordinal measures is to treat the data as interval, as long as the researcher is alert to the possibility of measurement inequalities (28:432). Analysis of the survey results was accomplished using hypothesis testing of the mean responses for each question. First, the mean and standard deviation of responses were computed for the entire sample. Means and standard deviations were then computed for two subdivisions of the sample: (1) members of the R&M Review Council, and (2) R&M Quality Team members.

In order to draw conclusions about the survey responses, hypotheses about the mean response values were constructed. Null and alternative (research) hypotheses to be tested were established for responses to survey questions 5, 6, 7, and 8. The assumption was made

that, in the case of each question, responses above the value 3 indicated a positive opinion about the issue addressed. The null hypothesis for each of the four scaled questions was constructed as follows:

$$H_o: \text{mean response} \leq 3$$

By comparison, this is the alternative hypothesis which the research sought to affirm:

$$H_a: \text{mean response} > 3$$

Null and alternative hypothesis for each question were phrased in the context of the survey questions examined.

After the mean and standard deviations of the survey data were calculated, numerical values of selected test statistics were determined. The statistics used in the hypothesis testing were z-scores and t statistics. Z-scores are useful for hypothesis testing when a sample size is relatively large, and t statistics are useful for making inferences about small samples. An arbitrary sample size of 30 is a common cutoff between using large and small-sample techniques since, as a sample increases in size, the difference between the values of z and t decreases (33:303). Because the sample was relatively large, z-scores were used for hypothesis testing of the survey results for the entire DAC employee sample. In the analysis of survey results from R&M Review Council members, t statistics were used in hypothesis testing because of the small sample size. Although not directly supporting a research question, the t statistic was also used to compare the difference in survey results between R&M Review Council Members and R&M Quality Team members. This testing was accomplished to

compare the opinions of DAC management as represented by the R&M Review Council with the opinions of DAC workers participating in R&M Quality Teams.

The ensuing sections describe the specific analyses applied to support the research questions. Hypothesis testing was used for analysis of data resulting from scaled survey questions only. Therefore, hypothesis testing was applied in analysis of data pertaining to research questions 1 and 2. Because data supporting research question 3 came from the open-ended survey question and interviews with DAC personnel, hypothesis testing was not applicable.

Analysis Supporting Research Question 1. Hypothesis testing was used to analyze the responses to survey questions 5 and 6. Research hypotheses were established for each survey question. The following research hypotheses supported research question 1, "How has the R&M Quality Team Concept affected communication on R&M issues between C-17 program organizations and between those organizations and management?"

H_a: The R&M Quality Team Concept has positively affected communication on R&M issues between C-17 program organizations.

H_a: Communication between the R&M Review Council and R&M Quality Teams is better than adequate.

Analysis Supporting Research Question 2. Hypothesis testing was also used to analyze the responses to survey questions 7 and 8. Research hypotheses for each survey question were constructed to evaluate research question 2, "How do DAC personnel perceive the R&M Quality Team's impact on the C-17 R&M design process?"

H_a: The R&M Quality Team Concept has been valuable in solving C-17 design reliability and maintainability problems.

H_0: Overall, the R&M Quality Team process has been valuable as it has been applied to C-17 design.

Analysis Supporting Research Question 3. Data gathered to support research question 3 were qualitative rather than quantitative in nature. In analyzing the data, responses to survey question 9 and interviews were compiled and presented in a narrative format to determine what contributions the R&M Quality Team Concept made to R&M in C-17 design. Results of the data analysis used in this research are presented in Chapter IV.

Limitations

The most significant hurdle anticipated in this research was getting unbiased responses from the surveyed population and individuals interviewed. The aerospace industry is well aware of the importance the Air Force places on R&M 2000, and responses to interviews and the survey could have reflected bias on the part of individuals looking out for their company's image. Specific examples of improvements resulting from the R&M Quality Team Concept were intended to help diminish the impact of favorable bias and lend support to any favorable effects of the concept as cited by respondents.

Another potential limitation of the research was the use of hypothesis testing on ordinal data extracted from opinion survey. While the hypothesis testing was useful in drawing conclusions about the survey results, the survey data used for the testing was strictly personal opinion as expressed by DAC employees. As such, pronouncements concerning the success or failure of the R&M Quality Teams based solely on employee opinion should be carefully examined.

In-depth interviews were conducted and tangible examples of R&M Quality Team Concept successes were sought in an effort to prevent judgement of the concept solely on the basis of the personal opinion survey.

Although companies other than DAC are applying the R&M Quality Team Concept to their organizations, the focus of this study is limited to use of the concept by DAC in the C-17 program. Because of resource constraints, comparisons were not made between DAC's implementation of the concept and the experiences of other companies. Research results should, however, be generalizable to any organization considering the usefulness and practicality of applying the R&M Quality Team Concept as a means to encourage R&M management commitment and promote product quality. The following chapter presents the research results.

IV. Results

Introduction

This chapter reveals findings from field research at DAC's Long Beach, California, C-17 engineering facility. First, the C-17 program organization will be described with emphasis on the areas affected by the R&M Quality Team Concept in order to better understand the concept's impact on organizational communication and problem solving. DAC initiatives which facilitated the R&M Quality Team Concept's implementation will also be addressed. Next, research results within the framework of each research question will be considered. For research questions 1 and 2, results of hypothesis testing will be presented. Lastly, survey and interview responses answering research question 3 will be examined.

DAC C-17 Program Organization

The myriad and complex tasks associated with design and manufacture of the C-17 are organizationally under the purview of a DAC Vice President who serves as General Manager of the C-17 program. Portions of the organization directly involved with the R&M Quality Team Concept are Program Engineering and Integrated Logistics Support (ILS).

Under Program Engineering, the organization is further subdivided into Design Engineering and System Engineering groups (Figure 2). Design Engineering accomplishes all design drawings and is organized by specific aircraft system. System Engineering's chief participant in

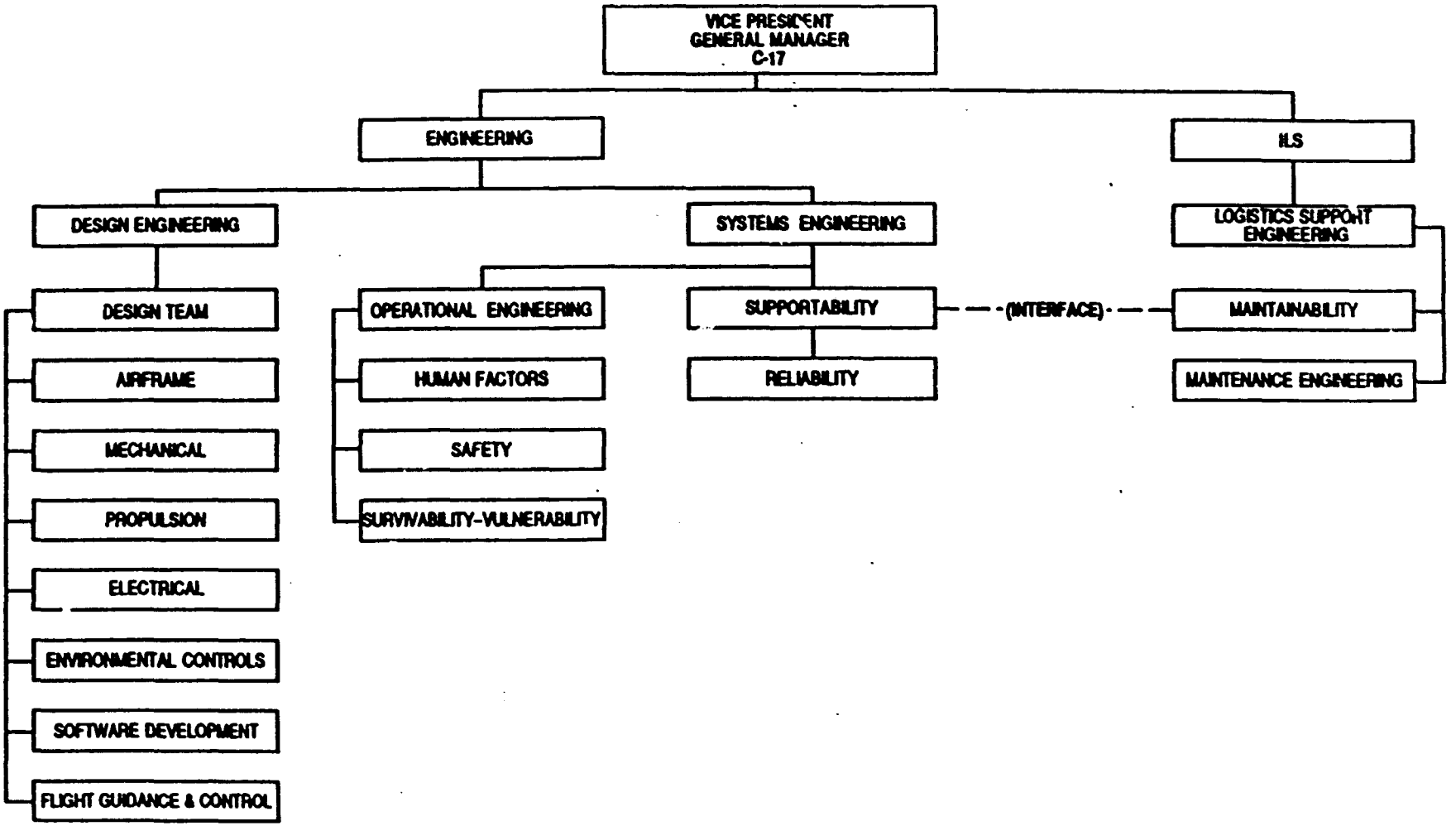

Figure 2. C-17 Program Partial Organization Chart (9)

the R&M Quality Team Concept is Supportability Engineering. Among Supportability Engineering's responsibilities are computation and monitoring of system R&M measures (e.g., mean time between maintenance, mean time between removal, and probability of failure) based on design engineering drawings.

ILS participates in the R&M Quality Team Concept through Logistics Support Engineering. Under Logistics Support Engineering, Maintainability serves as an interface between the ILS and System Engineering functions (Figure 2). The Maintainability Manager reports to the Chief of Logistics Support Engineering and provides information to System Engineering through the Chief Supportability Engineer. Maintainability personnel compute such maintenance measures as mean manhours to repair and maintenance manhours per flying hour.

The R&M challenge for C-17 program management was to foster an integrated approach in developing the aircraft. Such an approach would ideally "make design, logistics, R&M, and production engineers one interactive team" (7:14). According to Mr Shel Hess, DAC Director of Product System Engineering and former Manager of C-17 System Engineering, DAC recognized the necessity of engineering integration in C-17 design from the outset of program development. He claimed the R&M Quality Team Concept was established as a management initiative to encourage "collaborative problem solving" among members of the engineering departments. DAC instituted several other organizational techniques unique to the C-17 program to promote integration of effort in aircraft design. Mr Hess further stated these methods facilitated implementation of the R&M Quality Team Concept as devised by Major

Guzzi (24). The techniques included Design Decision Notices (DDNs), Review and Comment Sheet/Design Action Requests (R&CS/DARs), and engineering design teams.

Design Decision Notice. The purpose of DDNs is to provide notification to all affected engineering groups concerning significant engineering design decisions (10). DDNs are intended to permit thorough review of design changes. Although not exclusively an R&M initiative, DDNs are useful in informing Systems Engineering of design modifications, thereby enabling the Reliability and Maintainability groups to assess the modification's impact on R&M measures (8). Appendix B shows a sample DDN form.

Review and Comment Sheet/Design Action Request. The R&CS/DAR was developed as a means to permit members of C-17 engineering groups to "optimize the C-17 design among the multiplicity of design considerations" (15). It provides a method for members of engineering groups outside of Design Engineering to express concerns about design features, and recommend possible design improvements or modifications. Like the DDN, the R&CS/DAR enables Reliability and Maintainability engineers to become more involved in the design process. According to Mr John Dorris, Chief of C-17 Supportability Engineering, R&CS/DARs have resulted in many R&M improvements in C-17 design (8). Sample R&CS/DAR documentation is contained in Appendix C.

Engineering Design Teams. In an effort to strengthen personal communication on design issues, C-17 program management created engineering design teams. Unlike R&M Quality Teams, which operate under a temporary charter to address a specific problem, engineering

design teams are established on a more permanent basis and are organized by aircraft system (e.g., flight controls, hydraulic power, and landing gear). Individuals from across the engineering groups are assigned to an engineering design team in order to contribute to the design process for a particular aircraft system. Each engineering design team has at least one representative from the following groups: Reliability, Maintainability, Maintenance Engineering, Safety, Survivability/Vulnerability, Human Factors, and Design (8). Members of engineering design teams participate in engineering review meetings "when required to discuss design problems and alternative solutions" (10:2). Members also review DDNs for their particular system.

DAC engineers interviewed generally agreed that DDNs, R&CS/DARs, and engineering design teams promoted dialogue on system engineering issues and encouraged an integrated approach to C-17 design. However, these initiatives did not address the issue of managing overall R&M system quality. The R&M Quality Team Concept was instituted by DAC to provide: (1) management of system quality through the R&M Review Council, and (2) innovative problem solving through ad hoc formation of R&M Quality Teams (24). Members of DAC engineering management expressed the opinion that the DDNs, R&CS/DARs, and engineering design teams dealt with day-to-day R&M and integration issues. Management believed this complemented implementation of the R&M Quality Team Concept by allowing the R&M Review Council to focus on broader, "top level" concerns affecting the entire program (8,24,40). Integrating efforts of different engineering groups within the

organization can lead to disagreements concerning what design tradeoffs, if any, should be made. Several engineers interviewed described how, prior to the advent of the R&M Review Council, resolving differences of opinion about various design considerations often depended on the dominance of individual personalities. The Chief of C-17 Design Engineering, Mr D. H. Siegele, said R&M engineers had to "pressure" design offices as R&M problems arose under the "old" system of aircraft design and system engineering. He continued by stating that currently "the Review Council eliminates doubt about chosen courses of managerial action" (44). The R&M Review Council functions as the "supreme court of conflicts between design and supportability," according to Mr Hess (24).

In summary, engineering integration methods implemented by DAC management for the C-17 program were intended to promote interaction between organizations within the program. Ideally, such interaction results in a final product which satisfies customer requirements, including R&M criteria. The R&M Quality Team Concept was one method applied by DAC to further engineering integration. The following sections discuss survey and interview findings relating to the R&M Quality Team Concept and its effectiveness as perceived by DAC personnel.

Survey Response Rates

A total of 56 surveys were completed and returned out of 110 surveys distributed to DAC employees, for an overall response rate of 51%. Of the 10 surveys distributed to present or former members of the R&M Review Council, 5 were returned for a response rate of 50%. Among

the remaining surveys, 46 were completed by members of R&M Quality Teams. Five of the respondents were neither Review Council or Quality Team members, but were familiar with the R&M Quality Team Concept, having been invited to R&M Review Council meetings or observed R&M Quality Teams at work. Responses to scaled survey questions are presented at Appendix D.

Survey and Interview Analysis

This section examines the survey and interview results from field research in the context of the three research questions as presented in Chapter I. Research questions will be restated for each subsection. The results of hypothesis testing for research questions 1 and 2 are presented in Tables 2 through 5.

Research Question 1: How has the R&M Quality Team Concept affected communication on R&M issues between C-17 program organizations within DAC [horizontal communication], and between those organizations and management [vertical communication]?

Horizontal Communication. The following null and alternative hypotheses were established for survey question 5 to assess opinion on the R&M Quality Team Concept's impact on communication between C-17 program organizations (e.g., design, reliability, and maintainability):

H_0: The R&M Quality Team Concept has not affected, or has detrimentally affected, communication on R&M issues between C-17 program organizations.

H_a: The R&M Quality Team Concept has positively affected communication on R&M issues between C-17 program organizations.

Based on the statistics computed from the survey responses (Table 2), the null hypothesis is rejected. The probability of falsely

Table 2. DAC R&M Quality Team Concept Survey Results: Horizontal Communication *

Sample (sample size)	Mean	SD	z or t score
Total Sample (n = 56)	4.27	0.88	10.41 **
R&M Review Council (n = 5)	4.8	0.4	10.06 **
R&M Quality Teams (n = 46)	4.19	0.91	8.47 **
T-test of Difference Between Review Council and Quality Team Means			1.47 ***

Notes:
* 1 = Detrimental Effect, 3 = No Effect, 5 = Positive Effect
** $p < .005$
*** $p < .01$

rejecting the null hypothesis is well below the .005 level. The t-test comparing R&M Review Council and R&M Quality Team participant responses was significant at the .01 level.

A majority of respondents to survey question 5 made written comments to the effect that the R&M Quality Team Concept provided a way for members of different organizations to work toward a common goal. Others said the interface between engineering groups brought problems to light and resolved them. One respondent wrote the concept was "useful for interdivisional communication" with Safety, Reliability, Maintainability, and Design working together to improve systems and procedures. In the opinion of many, R&M Quality Teams facilitated communication on major complex problems.

Potential dilemmas expressed by survey respondents included the "them and us" orientation to R&M issues which sometimes still exists between Design and System Engineering. As one respondent wrote, "the Quality Teams help, but everyone wants the other guy to do the work." Potential to get "carried away" calling meetings, potentially "wasting time" was also mentioned. One respondent replied, "Action items, verifications, and justifications add additional work burdens." Another stated, "Had more collaboration between engineering occurred at the outset [of design], not as many problems would need to be solved after the fact."

Vertical Communication. Responses to survey question 6 were tested using the following null and alternative hypotheses:

H_0: Communication between the R&M Review Council and R&M Quality Teams is less than adequate.

H_8: Communication between the R&M Review Council and R&M Quality Teams is better than adequate.

Once again, the statistics computed from survey results in Table 3 lead to rejection of the null hypothesis. Survey responses indicate DAC employees generally perceive communication between the R&M Review Council and R&M Quality Teams to be better than adequate. However, the z-scores and t-scores generated by the responses, although significant, were lower than for any other survey question. This held for both R&M Review Council and R&M Quality Team members. Survey question 6 also had the highest number of no responses (16%) from individuals who otherwise completed the survey. The t-test comparing the difference between R&M Review Council and R&M Quality Team member mean responses was not statistically significant.

The range of written responses to survey question 6 varied from extremely positive opinions to some dissatisfaction with the R&M Review Council's communication with Quality Teams. Several of the comments referred to "very good," "open," and "positive" lines of vertical communication. One R&M Review Council member mentioned that while generally excellent communication took place and participants were enthusiastic, "a few crossed signals" occurred between the Review Council and the Quality Team's charter. Many Quality Team members expressed the desire for more feedback from the Review Council. Several Quality Team members also contended they were occasionally uncertain of what the directives of the Review Council were. From a management perspective, a Review Council member stated more frequent reports from Quality Teams would improve vertical communication by keeping the council better apprised of team progress.

Table 3. DAC R&M Quality Team Concept Survey Results:
Vertical Communication *

Sample (sample size)	Mean	SD	z or t score
Total Sample (n = 56)	3.7	1.15	4.17 **
R&M Review Council (n = 5)	4.25	0.43	5.81 **
R&M Quality Teams (n = 46)	3.63	1.22	3.18 **
T-test of Difference Between Review Council and Quality Team Means			0.74

Notes:
* 1 = Poor Communication, 3 = Adequate Communication,
5 = Excellent Communication
** $p < .005$

Research Question 2: How do DAC personnel perceive the R&M Quality Team Concept's impact on the C-17 R&M design process?

Solving Design R&M Problems. The following null and alternative hypotheses were established for survey question 7:

H_0: The R&M Quality Team Concept has had little or no value in solving C-17 design reliability and maintainability problems.

H_a: The R&M Quality Team Concept has been valuable in solving C-17 design reliability and maintainability problems.

Survey results for question 7 support rejection of the null hypothesis (Table 4). Z-scores for the total sample and R&M Quality Team participants, and the t-score for Review Council members all substantiate the alternative hypothesis that the R&M Quality Team Concept has had value in solving design R&M problems. A comparison of mean responses between Review Council members and Quality Team participants shows no statistically significant difference.

Written comments following this survey question related how problem solving improved as a result of enhanced communication between engineering groups. One team member stated the R&M Quality Team process had been extremely valuable in solving design problems because "we have improved the communications not only among the design, maintainability, and reliability communities, but also with other functional and supporting organizations." Others mentioned the advantage of each R&M Quality Team member contributing engineering experience toward solving design problems. Several respondents expressed the value of the R&M Quality Team process in reducing failure rates by permitting more thorough design reviews and analyses of assumptions input to the failure rate computations. Another Quality

Table 4. DAC R&M Quality Team Concept Survey Results:
R&M Problem Solving Value *

Sample (sample size)	Mean	SD	z or t score
Total Sample (n = 56)	3.87	0.94	6.8 **
R&M Review Council (n = 5)	4.2	0.4	6.71 **
R&M Quality Teams (n = 46)	3.82	0.98	5.55 **
T-test of Difference Between Review Council and Quality Team Means			0.62

Notes:
* 1 = Not Valuable, 3 = Somewhat Valuable,
5 = Extremely Valuable
** $p < .005$

Team participant asserted the value of the R&M Quality Team Concept in solving design R&M problems resulted from "promoting broader system understanding among the designers." Most Review Council members stressed how the concept strengthened managerial "focus on significant issues." One council member explained how the R&M Quality Team process was most effective at solving "system process" problems, and that detailed design problems were handled mostly by DDN and R&CS/DAR procedures.

The few negative written comments received from R&M Quality Team members primarily centered on the increased amount of time necessary to work problems when more people are involved. Another concern mentioned was the necessity of having capable people as members of Quality Teams -- individuals who understand the design and are able to provide adequate input. One respondent claimed when the Review Council did not clearly communicate the problem to be addressed, problem solving effectiveness of the Quality Team was reduced.

Overall Opinion of R&M Quality Team Concept. The following null and alternative hypotheses were constructed for research question 8:

H_0: Overall, the R&M Quality Team Concept has had little or no value as it has been applied to C-17 design.

H_a: Overall, the R&M Quality Team Concept has been valuable as it has been applied to C-17 design.

Again, the z-scores and t-scores resulting from survey responses prove to be significant (Table 5). Therefore, the results substantiate the alternative hypothesis. In addition, no significant difference exists

Table 5. DAC R&M Quality Team Concept Survey Results:
Overall Opinion of Process *

Sample (sample size)	Mean	SD	z or t score
Total Sample (n = 56)	3.96	0.88	8.02 **
R&M Review Council (n = 5)	4.4	0.49	6.39 **
R&M Quality Teams (n = 46)	3.91	0.9	6.71 **
T-test of Difference Between Review Council and Quality Team Means			0.77

Notes:
* 1 = Not Valuable, 3 = Somewhat Valuable,
5 = Extremely Valuable
** $p < .005$

between mean responses of R&M Review Council and R&M Quality Team members.

The majority of written comments to this survey question emphasized the value of teamwork across engineering communities in improving design R&M for the C-17. Improved problem solving resulting from team efforts was mentioned as being of extreme value in the C-17 design effort. One Quality Team member claimed the R&M Quality Team process "forces" designers and R&M engineers to "work as a combined team." Another benefit described by a Quality Team member was how the R&M Quality Team process "helps the design community better understand the R&M 2000 initiatives and the overall goal of achieving a product of optimum life-cycle cost."

Again cited as a potentially adverse effect of the R&M Quality Team Concept upon the C-17 design process was the increased amount of time to accomplish the coordination required for a team effort in solving problems. In addition, several engineers expressed dissatisfaction with the amount of feedback received for their efforts on problem areas assigned by the R&M Review Council. One Quality Team member felt team efforts were "equivalent to previous DAC R&M/design engineering coordination," and did not know the R&M Quality Team Concept's design impact. Other Quality Team members shared this uncertainty about what the overall consequences of the R&M Quality Team Concept had been as applied to C-17 design. As a team member stated "the benefits even of an actively pursued R&M effort are, to me, hard to identify during design."

Research Question 3: What contributions has the R&M Quality Team Concept made to R&M in C-17 design?

Survey question 9 addressed this research question by asking subjects to list examples of C-17 design changes directly resulting from the R&M Quality Team process. Because of differences in the nature of survey responses between R&M Review Council and R&M Quality Team members, results for each group will be presented separately. First, survey and interview responses from Review Council members will be presented, followed by survey replies from Quality Team participants.

R&M Review Council. Of five respondents, only one listed specific design changes. The other R&M Review Council members wrote statements to the effect that most of the issues handled by the R&M Quality Teams have been to solve procedural and process problems rather than to make specific design changes. When asked what was meant by "procedural and process problems," Mr John Lindley, Chief of C-17 Systems Engineering, explained the R&M Quality Team Concept strengthened working relationships between Reliability, Maintainability, and Design in addressing problems affecting broad, system-level issues (29). An example of a system-level problem would be a predicted reliability or maintainability measure for the aircraft not meeting contractual requirements (24). In describing the relationship between the R&M Quality Team Concept and design changes, Mr Dorris stated attributing specific design changes exclusively to the efforts of R&M Quality Teams is difficult (8). While focusing on problem areas assigned by the Review Council, the Quality Teams become

involved in everyday engineering activities. DDNs and R&CS/DARs are routinely used by Quality Teams. In addition, the Quality Teams are often composed of members of the same engineering design team. Consequently, "it is often impossible to separate actions that are purely the result of the Quality Teams and actions acted upon by the teams, but actually originated by traditional DAC business methods" (14:1).

Despite the apparent difficulty in directly attributing specific design changes to the R&M Quality Team Concept, Review Council members did cite examples of major efforts by Quality Teams which influenced C-17 design R&M. Council members also stated that some specific design changes did result from the Quality Teams' work on system-level problems. Two prominent efforts mentioned in both the surveys and interviews focused on the following problem areas: (1) mean time between maintenance (corrective) (MTBM(C)), and (2) failure mode effect and criticality analysis (FMECA). Subsequent sections describe how actions of the R&M Review Council and R&M Quality Teams influenced each of these areas.

MTBM(C). Mean time between maintenance (corrective) is a reliability measure relating to all corrective on-equipment maintenance events (12:2). According to Mr Hess, MTBM(C) was "out of control" during approximately the same time C-17 program management was establishing the R&M Review Council in late 1985 (24). The predicted MTBM(C) as of 5 November 1985 was 0.68 hours compared to a contractual requirement of 0.78 hours (12:4).

The newly formed R&M Review Council approached the discrepancy in MTBM(C) by using engineering design teams as R&M Quality Teams to examine the following three areas: (1) credibility of system descriptions, (2) comparability analyses forming the basis of the predictions, and (3) adequacy of design in "high driver areas" (13:2). "High drivers" were those systems which potentially reduced the overall MTBM(C) for the aircraft.

R&M Quality Team design scrutiny of MTBM(C) resulted in several key changes which improved design R&M. For example, review of the landing gear design revealed the possibility of reducing the number of hydraulic hoses, fittings, and swivels in the extension/retraction system. Consequently, the landing gear design was simplified (14:2). The total number of landing gear parts decreased to 15, compared to 117 parts in the landing gear for the C-5A (41:7). In another example, MTBM(C) analysis resulted in reducing the number of fittings and connections in the hydraulic system plumbing (14:2). Interior and exterior lighting systems also benefited from the MTBM(C) review. Planned interior lamps had a rated life of 300 hours, the same as C-5 and C-141 lamps. The specification for C-17 interior lamps was boosted to 1000 hour rated life. Landing and wing inspection lights in use on current transport aircraft have useful lives of 25 and 10 hours respectively. Requirements for C-17 landing and wing inspection lights were increased to 100 and 500 hours. In addition, vibration resistant lamps and assemblies were developed to further improve reliability (14:2). As a result of R&M Quality Team actions, projected MTBM(C) improved beyond the contractual requirement.

FMECA. The failure mode effect and criticality analysis is a "design tool" which "identifies possible system failures, the causes of these failures, the effects of failure on the system and the criticality in terms of safety and mission accomplishment. . ." (2:206). The FMECA is implemented by reliability engineering, and FMECA results are a significant part of the data generated from the initial logistics support analysis (LSA) (2:208). For the C-17, DAC Integrated Logistics Support agreed to conduct a LSA requiring more detailed FMECA data than Supportability Engineering originally expected to provide. Data required included more specific information on failure rates and failure probabilities for all reparable line replaceable units, and detailed indications of system failures to maintenance personnel and flight crew. Without this data, the LSA could not be conducted on schedule (24).

In early 1986, the R&M Review Council convened to determine how to direct engineering efforts in computing the required FMECA data. R&M Quality Teams were established from engineering design teams in order to analyze all major aircraft systems. Focus of the R&M Quality Teams was first directed toward FMECAs for the top 20% "drivers" -- those aircraft systems most prominent in failure estimates. This "truncated" FMECA generated data necessary to complete the initial LSA (8).

After accomplishing the truncated FMECAs, the Quality Teams were chartered by the Review Council to complete FMECAs for the entire aircraft. According to Review Council members, Quality Teams discovered problems in the FMECA development plan while working on the FMECAs. The teams determined FMECA schedules and worksheets were not

adequately supporting "Critical Design Review" deliverable needs, including "the second iteration of the LSA on the entire aircraft and the timely critique of the C-17 detailed design" (13:2). Based on the needs of FMECA users, a Quality Team redesigned FMECA forms and developed a "FMECA recovery plan" (14:8). The plan called for unbudgeted increases in manpower in Engineering and ILS. Through the Review Council, the plan was presented to program management, and additional funding for increased manpower was provided by the C-17 Program Office (14:8).

Besides correcting deficiencies in the overall FMECA process, the efforts of R&M Quality Teams in conducting FMECAs produced aircraft design R&M improvements. For example, while developing the aileron control system FMECA, a Quality Team discovered a potentially serious "single-point" failure that could cause the aileron to bind. Consequently, the aileron control system was redesigned to eliminate the single point failure. "Because the team was developing the FMECA concurrent with the design development, the problem was detected early enough to make the redesign effort simple and inexpensive" (14:10-11). In another example, the FMECA effort influenced design R&M of the landing gear system. As a consequence of conducting the FMECA, Reliability, Maintainability, Maintenance Engineering, and Design engineers discussed the landing gear strut design, emphasizing the impact of landing gear strut seals, gauges, valves and hydraulic pressure on system R&M (16:2). According to members of the Review Council, efforts of Quality Teams permitted timely completion of the

FMECA, improvement of the FMECA process, and design changes which improved system R&M.

R&M Quality Team Participants. From the 46 surveys returned by R&M Quality Team members, 16 respondents, or 35%, stated they did not know of any design changes directly resulting from the R&M Quality Team Concept. Survey responses from 6 of the remaining 30 subjects addressed the impact of the R&M Quality Team Concept on various aspects of the design process. Specific design changes were listed by 24 respondents, or 52% of Quality Team members returning surveys. Survey results are presented under two categories: (1) the R&M Quality Team Concept's impact on the design process in general, and (2) specific design changes resulting from the R&M Quality Team Concept.

Impact on Design Process. Rather than listing specific design changes resulting from the R&M Quality Team Concept, 6 team members elected to describe how the concept impacted various aspects of the design process. Two individuals stated that, as a result of FMECAs accomplished by R&M Quality Teams, System and Design engineers were provided with more realistic failures by which design R&M could be evaluated. Other respondents claimed Quality Team review of MTBM(C) and mission completion success probability (MCSP) inputs helped insure the accuracy of data bases used to compute R&M measures. Assumptions underlying computation of these measures were reevaluated by Quality Teams, resulting in what one team member described as R&M projections more closely reflecting reality in the final product. Also stressed in survey responses was the value of including Reliability, Maintainability, and Design engineers as members of Quality Teams in

the MTBM(C) and MCSP investigations. The overall impact of Quality Teams on design R&M as expressed in the survey results was improved cooperation between engineering departments. Enhanced interface between departments resulted in what team members believed to be a more realistic portrayal of actual C-17 R&M.

Specific Design Changes. R&M Quality Team members listed design changes for a broad variety of aircraft systems. However, as reported by R&M Review Council members, several respondents remarked that attributing design changes exclusively to the efforts of Quality Teams was extremely difficult. This was because day-to-day work of engineering design teams often overlapped with the problem areas highlighted by Quality Teams. In addition, composition of Quality Teams was frequently the same as the engineering design teams. As a result, several survey respondents stated they were not certain whether the design changes listed arose solely from the efforts of Quality Teams or other engineering integration methods. Nonetheless, survey respondents indicated cooperation between engineering organizations promoted by the R&M Quality Team Concept helped facilitate many design changes which improved the R&M of aircraft systems. Landing gear, aileron control system, and interior and exterior lighting R&M enhancements mentioned by Review Council members were also listed by Quality Team participants. Other design changes enumerated by team members included changes to the aerial delivery system (ADS). While investigating MTBM(C), a Quality Team discovered the ADS control panel assembly required a disproportionate amount of maintenance. The analog ADS was redesigned as a digital system,

thereby replacing 104 control solenoids which had been the source of low reliability. This change improved the ADS control panel's reliability by a factor of 20 (14:4).

R&M Quality Team members also described how digital technology was used to simplify the hydraulic system. A digital control unit simplified hydraulic system design by eliminating existing hydromechanical valves and relays. The digital system additionally provided built-in-test and central failure monitoring and display capabilities unavailable with the original system. By modifying ADS computer software, the hydraulic system control unit became interchangeable with the ADS control unit, improving maintainability (14:3). To further simplify the system, the hydraulic fluid refill panel was eliminated and the ADS control panel was modified to display hydraulic fluid quantity.

Survey results outlined numerous design changes made to ease maintenance in the engine area. The hydraulic pump filter interfered with access to the engine fuel control unit, adversely affecting maintainability. The filter was redesigned, allowing adequate clearance to the fuel control unit. Access to the engine oil tank servicing area was improved by rerouting cables and redesigning cable brackets adjacent to the servicing area. To service the engine oil, the accessory compartment door had to be removed, "a very large and fairly heavy door with numerous fasteners" (14:5). A smaller "door-within-a-door" was designed for servicing the engine oil, eliminating the requirement to remove the entire accessory compartment door.

Other examples of design changes mentioned in the survey made

components within the pylon more accessible for maintenance. The pylon contains numerous connectors for major aircraft systems, including the electrical, hydraulic, fuel, and pneumatic systems. By redesigning the arrangement of connectors within the pylon, servicing accessibility was eased such that mean manhours to repair for the connectors improved over 100% (14:5). Thrust reverser valve arrangements were redesigned and relocated, not only improving accessibility, but also eliminating the need for an additional access door on the pylon.

Summary

Research revealed DAC employees had generally positive attitudes toward the R&M Quality Team Concept as implemented during C-17 Full-Scale Development. All four research hypotheses were statistically supported, both for managers comprising the R&M Review Council and lower-level engineers on the R&M Quality Teams. DAC employees also claimed the efforts of Quality Teams resulted in or influenced C-17 design changes, although other DAC engineering integration methods made precise identification of the impetus behind design changes difficult. Research results are addressed further in Chapter V.

V. Discussion, Conclusions, and Recommendations

Introduction

This chapter further reviews the research results for the R&M Quality Team Concept as applied by DAC to the C-17 program. Findings from the research are first discussed. Next, conclusions drawn from research results are presented. Lastly, recommendations for future research are suggested.

Discussion

The R&M Quality Team Concept was instituted by DAC management as a method to improve overall quality of the C-17 transport aircraft during the Full-Scale Engineering Development phase of weapon system acquisition. Because R&M are inherent to product quality, integrating R&M practices into the engineering design process is a major goal of the Air Force acquisition community (1:12). The primary benefit of successful engineering quality is increased war-fighting capability (1:20).

This research investigated the effect of the R&M Quality Team Concept on DAC's management of R&M during C-17 design. Three research questions presented in Chapter I established the study's framework. The remainder of this section will deal with research results in the context of each research question.

Research Question 1: Communication. The first research question asked how the R&M Quality Team Concept affected communication on R&M issues. Research hypotheses were established to determine the impact of the R&M Quality Team Concept on communication between

organizations in the C-17 program (horizontal communication), and between those organizations and management (vertical communication). The prevalent attitude among DAC employees, substantiated by survey and interview results, was the R&M Quality Team Concept has had a positive effect on horizontal and vertical communication concerning R&M issues.

Mean responses to the horizontal communication survey queation were higher than responses to any other scaled question. This may have been because of the R&M Quality Team Concept's impact in helping resolve a long-standing problem in engineering design integration. The problem stems from a tendency in American business organizations to fragment and decentralize organizational structure, thereby segregating technological expertise (23). DAC managers interviewed described this fragmentation as "silos" around each engineering department. Design engineers concentrated on designing individual systems, while Reliability and Maintainability engineers had little input to the design process. Historically, communication between members of different engineering departments was minimal. If R&M problems arose during design, they were resolved on the basis of individual efforts to elevate problems vertically through the organization to the top levels of management. The R&M Review Council provided a needed forum to prioritize R&M problems with input from managers of all engineering departments active in the R&M process (29). The Review Council then organized Quality Teams as necessary to deal with specific problem areas.

While DAC employees had overall positive attitudes toward the R&M Quality Team Concept's impact on horizontal communication, the mean

survey score of Review Council members was higher than that of Quality Team members at the .01 level of significance. This was perhaps a consequence of the R&M Review Council's broader perspective of the R&M Quality Team process. None of the other scaled survey responses revealed a statistically significant difference in overall responses between Review Council and Quality Team members.

Mean responses to the survey question on vertical communication, while positive, were lowest among scaled question responses. This question also had the largest number of non-responses by individuals who otherwise completed the survey. Many R&M Quality Team members were dissatisfied with the amount of feedback from the Review Council on the progress of team efforts. Minutes of weekly Review Council meetings, which record council activities and progress of Quality Teams, are distributed only among Review Council members and higher level management. In addition, Quality Team members interface with the council only when invited to attend the weekly meetings. A Review Council member stated that more frequent progress reports from Quality Teams would be beneficial in managing R&M problems, further indicating the usefulness of increased communication between the Review Council and Quality Teams.

The survey question concerning vertical communication also revealed confusion on the part of some R&M Quality Team participants as to the difference between engineering design teams and R&M Quality Teams, and the function of the R&M Review Council. This may have been due to the fact that several major Quality Team efforts were accomplished using established engineering design teams. It can be

argued that as long as communication takes place between engineering departments in solving problems, a group title is immaterial. However, efforts of Quality Team members may be more effective if members understand the significance of problem identification and prioritization by the Review Council, and why Quality Teams are formed to solve problems specified by the council.

Research Question 2: Impact On Design R&M. The second research question asked how DAC personnel perceive the R&M Quality Team Concept's impact on the C-17 R&M design process. Research hypotheses assessed the R&M Quality Team Concept's contribution in solving R&M problems, and the overall value of the concept as applied to C-17 design. Again, survey and interview results indicated DAC employees perceived the R&M Quality Team Concept as having a positive impact on C-17 design R&M.

According to DAC management, the R&M Quality Team Concept facilitated coordinated action on design R&M problems in a way which was previously nonexistent. Weekly Review Council meetings enabled engineering management to compare forecast R&M measures with contractual requirements, and, when necessary, collaborate in planning approaches to improve R&M. Managers reported the issues usually brought before the Review Council for consideration changed from "squabbles" between departments when the council was first established, to more difficult and complex problems as time progressed. This shift in the nature of problems dealt with by the Review Council may have been due to improvements in day-to-day communication between engineering departments. In addition, DAC managers believed existence

of the Review Council provided incentive for engineers to solve routine problems at the working level through established integration methods rather than elevate the problems to the attention of management (24).

Experienced DAC engineers perceived a greater emphasis on system R&M in the C-17 program compared to other projects. The R&M Quality Team Concept promoted this emphasis by giving Supportability, Reliability, and Maintainability managers a more prominent voice in the design decision-making process. A Review Council member stated that as recently as five years ago, R&M inputs to aircraft design were practically irrelevant. R&M considerations were afterthoughts considered once the aircraft was being produced. He now believed, however, the support given by top DAC management to initiatives such as the R&M Quality Team Concept indicated changing attitudes toward the importance of considering R&M early in the system acquisition process (29).

Despite assertions of the positive impact on design R&M caused by DAC's implementation of the R&M Quality Team Concept, the concept was not without employee criticism. First, some employees alleged the R&M Quality Team Concept fostered a "design by committee" approach which risked inefficiency. Individuals holding this view seemed to advocate a traditional aircraft design approach which minimizes interaction between engineering departments. Others asserted the ability of R&M Quality Team members to work together depended to a large degree on individual personalities. The DAC standard practice establishing R&M Quality Teams states "the authorized Quality Team is responsible for selection of its leadership from within its membership" (11:2). One

manager claimed Quality Teams often did not select a leader and, subsequently, effectiveness of the Quality Team in staying focused on the problem identified by the Review Council was diminished. Another complaint about the concept's application was that Quality Team members were often tasked with problems assigned by the Review Council while still being responsible for accomplishing normal job duties. Manning in the various engineering departments typically did not permit individuals to work exclusively on Quality Team projects, and some team members claimed allowances were not made for the addition workload.

Research Question 3: Examples of Accomplishments. The final research question asked what contributions the R&M Quality Team Concept made to R&M in C-17 design. Open-ended survey and structured interview questions asked respondents to identify specific design changes resulting from application of the R&M Quality Team Concept. Generally, three types of replies were received. First, some respondents stated the R&M Quality Team Concept was applied to deal with broad, system-level problems rather than make specific design changes. Other individuals actually listed design changes thought to have been the result of R&M Quality Team action. The third kind of response indicated no knowledge of design changes resulting from efforts of Quality Teams.

The first response was the reaction of most Review Council members and some Quality Team participants. Major efforts such as the FMECA revision and MTBM "scrub" were cited as examples of system-level issues managed by applying the R&M Quality Team Concept. Many of the respondents stressed how attributing specific design changes to the

concept was difficult because of other engineering integration methods routinely used (e.g., Decision Design Notices and engineering design teams). Nevertheless, most respondents were aware of several specific design changes which they believed to be the result of Quality Team action. The changes resulted in R&M improvements for such systems as landing gear, hydraulics, and interior and exterior lighting.

Secondly, many respondents listed design changes which they believed to be the result of R&M Quality Team action. A majority of Quality Team participants gave this kind of response. Replies included design changes to the previously mentioned systems. Design changes to the aerial delivery system, hydraulic system, and engine compartment and pylon layout were also listed. Some of these responses were qualified with statements expressing uncertainty whether the design changes were the result of Quality Team actions or other engineering integration methods.

The third type of response indicated no knowledge of design changes resulting from the R&M Quality Team Concept. Two explanations for this kind of reply are possible. First, the Quality Team participants may have worked on problem areas which did not require or did not precipitate design changes, such as portions of the FMECA revision. Another possible explanation is an absence of feedback about successful design changes initiated by Quality Teams. No means of communication existed to inform Quality Team members whether recommended design changes were adopted.

Conclusions

The R&M Quality Team Concept as instituted by DAC made valuable contributions to the system management of R&M during C-17 design. The concept provided engineering management with a method of participative decision making and problem solving not available in a traditional program organization. Activities of the Review Council and Quality Teams elevated the perceived significance of R&M and increased emphasis on R&M considerations during the design process.

Accomplishments engendered by the R&M Quality Team Concept would not have been possible without management resolution to improve C-17 R&M. According to David A. Garvin of the Harvard Business School, the first step to improving product quality is top management commitment (18). Commitment on the part of DAC management was evidenced by the incorporation of methods unique to the C-17 program which promoted engineering integration on a daily basis, such as Design Decision Notices and Review and Comment Sheet/Design Action Requests. DAC management also recognized the need for a new approach to manage R&M during the design process. Top program management endorsed the R&M Quality Team Concept as a unique approach to manage system-level R&M, and formally established it as company standard practice. Weekly Review Council meetings maintained R&M emphasis and kept engineering leadership involved in monitoring R&M (8).

DAC employees perceived one of the concept's most significant contributions to be enhanced communication between C-17 program organizations. Lack of interdepartmental communication detracts from the systems engineering process and the ability to incorporate R&M into

design. The R&M Review Council provided a forum for communication between engineering managers, while R&M Quality Teams enabled members of different engineering departments to collaborate in solving problems assigned by the council.

Although vertical communication between the Review Council and Quality Teams was regarded by most employees surveyed to be better than adequate, two factors detracted from this type of communication. First, many employees perceived a lack of feedback between the Review Council and Quality Teams. More frequent contact between Quality Teams and the Review Council, even in the form of informal, verbal reports, would help assure Quality Team efforts were on track and prevent "crossed signals" about what the team was to accomplish. A second factor which diminished vertical communication was unfamiliarity on the part of many employees about the R&M Quality Team Concept. Management established the concept with the intent that any employee could raise an issue to the Review Council for consideration (24). However, some confusion existed among Quality Team members about the concept's purpose and the Review Council's role in the process. Ensuring all employees, particularly Quality Team participants, are familiar with company standard practice on the R&M Quality Team Concept would assist in eliminating misconceptions and improve vertical communication.

Employees generally believed the R&M Quality Team Concept had value as an approach to solving R&M design problems. The Review Council was viewed as the "catalyst" for problem solving by monitoring system R&M and establishing Quality Teams as necessary. Quality Teams were formed when R&M tolerances, such as MTBM, were exceeded. Quality

Teams were also used when portions of the system engineering process, such as FMECA determination, were not functioning as desired by management. Management surmised the breadth of experience and expertise provided by a team approach to problem solving increased the probability of arriving at correct decisions (29). During the course of problem solving, Quality Teams often recommended and implemented design changes to enhance the R&M of specific aircraft systems (8).

The R&M Quality Team Concept, while not a panacea for product quality problems, has been endorsed by DAC as a practical method to improve organizational R&M management. As a result of successes within the C-17 program, DAC management intends to expand the concept's use to other programs and other acquisition phases (24). Application of the R&M Quality Team Concept in the C-17 program has been part of a learning process for DAC as the Air Force continues to underscore the importance of weapon system R&M. One significant consequence of DAC's R&M emphasis was that added working hours were required to give R&M increased consideration and achieve R&M requirements (44). The C-17 program experienced workload expansion in the form of such activities as additional R&M analyses, trade-off studies, and design revisions. Establishing engineering integration efforts from the program's outset would have probably reduced the number of design revisions required to achieve R&M objectives (24).

Continued application of the R&M Quality Team Concept by DAC appears linked to Air Force efforts toward making R&M equal with cost, schedule, and performance in weapon system acquisition. DAC is using the R&M Quality Team Concept to help manage the transition from

development to manufacturing. The most important step to establishing product quality in manufacturing is to "get the design people to work up front with the manufacturing people" (18). The Review Council and Quality Teams can potentially provide continued R&M focus during the production phase. For industry to institutionalize commitment to R&M and adopt initiatives such as the R&M Quality Team Concept, it is crucial for improved R&M and lower life-cycle costs to be intrinsic elements of Air Force acquisition policy.

Recommendations for Future Research

While DAC was the first company to actively apply the R&M Quality Team Concept, other industries have also expressed interest in the concept, as discussed in Chapter II. Continued research on the R&M Quality Team Concept will further reveal its merit as a quality management initiative. Research can also show whether DAC's experiences with the concept are applicable to other companies. In particular, the following two areas are suggested for research:

1. Follow-on research should be conducted to examine how the R&M Quality Team Concept is used by DAC to transition from the Full-Scale Development phase to the Production phase of C-17 acquisition. Such research should focus on how manufacturing is represented in the Review Council, and what areas receive predominant Review Council attention. Research should also compare forecast R&M measures in areas worked on by Quality Teams (e.g., MTBM(C) and MCSP) to actual C-17 performance.

2. Research examining application of the R&M Quality Team Concept to other companies should also be conducted. A method combining both interview and survey measures could determine employee attitudes toward

the concept and tangible results of concept application. Research should focus on what environmental conditions are conducive to concept effectiveness. Research should also address the extent to which the concept can be successfully generalized to other companies.

Summary

The benefits of improving weapon system quality have been recognized by top Air Force leadership, and R&M are viewed as significant quality contributors. Because there are no quick fixes in developing successful quality programs, commitment by the Air Force and industry alike must be long-term, and must demand innovation in finding methods to boost quality during weapon system acquisition. In the case of DAC's C-17 development, the R&M Quality Team Concept has proven itself as one way to advance organizational R&M commitment and improve management's ability to handle system-level R&M problems. While not a cure-all for dealing with R&M issues, the R&M Quality Team Concept encourages communication between traditionally segmented departments within an organization, and provides a medium for unified management action in addressing R&M concerns. The R&M Quality Team Concept's value exists in its contribution as part of a broad strategy to enhance weapon system quality. Successful realization of that strategy will improve the combat effectiveness of our armed forces.

Appendix A: R&M Quality Team Concept Survey

1. What is your department and office symbol at DAC?

2. What is your position within that department?

3. How have you been involved with R&M Quality Teams? (check one):

_____ R&M Review Council Member _____ R&M Quality Team Member

_____ Other (please specify): _____

4. How long have you been involved in the R&M Quality Team process?

5. How has the Quality Team process affected communication on R&M issues between C-17 program organizations (e.g., design, systems and logistics support engineering, and functional departments within each organization) (circle the appropriate choice):

1	2	3	4	5
DETRIMENTAL EFFECT		NO EFFECT		POSITIVE EFFECT

Comments:

6. How would you evaluate communication between the R&M Review Council and R&M Quality Teams (e.g., R&M Review Council's communication of objectives to R&M Quality Teams, receptivity of R&M Review Council to R&M Quality Team recommendations)?

1	2	3	4	5
POOR COMMUNICATION		ADEQUATE COMMUNICATION		EXCELLENT COMMUNICATION

Comments:

7. How valuable has the R&M Quality Team process been in solving C-17 design reliability and maintainability problems?

1	2	3	4	5
NOT VALUABLE		SOMEWHAT VALUABLE		EXTREMELY VALUABLE

Comments:

8. What is your overall opinion of the R&M Quality Team process as it has been applied to C-17 design?

1	2	3	4	5
NOT VALUABLE		SOMEWHAT VALUABLE		EXTREMELY VALUABLE

Comments:

9. List any examples of C-17 design changes you know of directly resulting from the R&M Quality Team process. Did each change improve reliability, maintainability, or both? (please specify):

(1).

(2).

(3).

(4).

Thank you for your participation.

Appendix B: Design Decision Notice Form

C-17 DESIGN DECISION NOTICE

Distribution limited to U.S. Government agencies only; Test and Evaluation; Other requests for this document must be referred to USAF/AFSC Code PQ7615.

NO. _____

DATE _____

REVISED _____

Page 1 of _____

SUBJECT:

COGNIZANT ORGANIZATION _____

DESIGN DECISION MEETING DATE _____ AUTHOR _____

SUMMARY OF ISSUES AND ALTERNATIVES:

DECISION:

SUMMARY OF RATIONALE AND IMPACT:

C-17 SPEC/SOW CHANGE REQUIRED: ☐ YES ☐ NO IDENTIFY/PARAGRAPH NO.: _____

PROCUREMENT SPEC CHANGE REQUIRED: ☐ YES ☐ NO IDENTIFY: _____

SUBCONTRACTOR/MDC COMPONENT AFFECTED: ☐ YES ☐ NO IDENTIFY: _____

CHANGE BOARD APPROVAL REQUIRED: ☐ YES ☐ NO

MANAGER – DESIGN	MANAGER – SYSTEMS ENGINEERING	DIRECTOR – ENGINEERING

Appendix C: Review and Comment Sheet/Design Action Request Forms

DAC 28-2413 (11-86)

C-17 ☐ REVIEW AND COMMENT SHEET (Copy to Designer) ☐ DESIGN ACTION REQUEST* (Copy to Chief-Design) LOG NO.:_____ DATE:_____ Pg 1 of ___

TO:_____ (Cognizant Designer) COPIES TO: WBS:_____

SUBJECT:_____ 863B/ WUC:_____

☐ DWG ☐ MOCKUP ☐ DEMO ☐ MTG ☐ OTHER:

EVALUATION AND COMMENT:

MAGNITUDE: ☐ SIG ☐ MIN ☐ NEG

DIRECTION: ☐ FAV ☐ UNFAV

FROM: ☐ SS ☐ RL ☐ MN ☐ HF ☐ S/V ☐ SE ☐ BIT ☐ SD ☐ LS

RECOMMENDATION/SUGGESTED ACTION:

NEGOTIATED SUSPENSE DATE: ☐ CLOSEOUT ☐ 1st STATUS BY: APPROVED:

STATUS/FOLLOW-UP: ☐ TO BE COMPLETED BY DESIGNER ☐ NOT REQD. INFO ONLY

DATE	STATUS / RESULTS / DECISIONS / PLANS:	OPEN/ CLOSED	BY	ORIGINATOR SIGNOFF O.K./ NOT O.K.

STATUS OF ISSUE AT CLOSEOUT:

MAGNITUDE ☐ SIG ☐ MIN ☐ NEG

DIRECTION ☐ FAV ☐ UNFAV

*Requires signature of Chief-Technology prior to issue

DESIGN REVIEW CHECKLIST — A ☐ FINAL ☐ REVIEW RETURN TO _____ BY _____	IMPACT ON: C-17 SYSTEM AMT			DIR		GROUP WORK AMT			DIR		DON NO / DATE: SUBJECT QUANTITATIVE/QUALITATIVE IMPACT AND COMMENTS	COGNIZ. INITIALS	REF OR ATTACH.
	NEGL	MIN	SIGN	FAV	UNFAV	NEGL	MIN	SIGN	INCR	DECR			
ACOUSTICS													
AERODYNAMICS													
AVIONICS													
CONTROLS													
ELECTRICAL													
ENVIRONMENTAL													
HYDRAULICS/ LANDING GEAR													
MISSION SYSTEMS													
PROPULSION													
SOFTWARE MANAGEMENT													
STRUCTURAL ANALYSIS													
STRUCTURAL DESIGN													
WEIGHTS											ΔW = LB		

DESIGN REVIEW CHECKLIST – B ☐ FINAL ☐ REVIEW RETURN TO _____ BY _____	IMPACT ON:											DDN NO.: DATE: SUBJECT. QUANTITATIVE/QUALITATIVE IMPACT AND COMMENTS	COORD. INITIALS	REF OR ATTACH.
	C-17 SYSTEM					GROUP WORK								
	AMT			DIR		AMT			DIR					
	NEGL	MIN	SIGN	FAV	UNFAV	NEGL	MIN	SIGN	INCR	DECR				
FLIGHT OPERATIONS														
HUMAN FACTORS														
SUPPORTABILITY – RELIABILITY (MTBF)														
SUPPORTABILITY – RELIABILITY (MCSP)														
SUPPORTABILITY – MAINTAINABILITY												Δ MMH/FH =		
SUPPORTABILITY – SUPPORT EQUIPMENT														
SUPPORTABILITY – LOGISTICS SUPPORT ANALYSIS												LSAR CHANGE: Y ☐ N ☐		
SUPPORTABILITY – OVERALL IMPACT														
SAFETY														
SURVIVABILITY/ VULNERABILITY														
STANDARDS														
PRODUCIBILITY														
MATERIALS AND PROCESS														
DESIGN TO LIFE-CYCLE COST												Δ LCC = $ MIL		

Appendix D: Survey Results Summary

R&M Review Council Member Responses

Council Member	Survey Question Number 5	6	7	8
1	5	4	4	5
2	5	5	4	5
3	5	4	4	4
4	4		4	4
5	5	4	5	4
Mean	4.8	4.25	4.2	4.4
Standard Deviation	0.4	0.43	0.4	0.49

R&M Quality Team Member Responses

Team Member	Survey Question Number 5	6	7	8
1	4	3		3
2	5			3
3	5	5	4	4
4	3		2	
5	4	3	3	3
6	4		3	4
7	3	1	2	2
8	4		3	4
9	5	5	5	5
10	5	4	5	5
11	5	5	5	5
12	3	3	4	4
13	5	4	5	5
14	4	4	4	4
15	5	5	5	4
16	5	5	4	5
17	5	4	4	4
18		2	4	4
19	3	3	3	3
20	5	5	5	5

R&M Quality Team Member Responses (continued)

Team Member	Survey Question Number 5	6	7	8
21	5	4	5	5
22			4	4
23	2	2	2	2
24	4	4	4	4
25	4	5	5	5
26	4	3	3	3
27	3	3	4	4
28	5	5	5	5
29		2	2	2
30	4	4	4	4
31	3		3	3
32	5	5	5	5
33	4	3		
34	5	5	4	4
35	4		4	4
36	5	4	4	4
37	5	4	4	4
38	3	2	3	4
39	4		5	4
40		3	2	3
41	5	5	5	5
42	5	4	4	5
43	3	2	3	3
44	5		4	4
45	5	5	4	4
46	2	1	2	2
Mean	4.19	3.63	3.82	3.91
Standard Deviation	0.91	1.22	0.98	0.9

Bibliography

1. Aeronautical Systems Division, Air Force Systems Command. "Aeronautical Systems Division Reliability and Maintainability Study." Briefing slides. ASD, Wright-Patterson AFB OH, 1987.

2. Blanchard, Benjamin S. Logistics Engineering and Management (Third Edition). Englewood Cliffs NJ: Prentice-Hall, Incorporated, 1986.

3. Daft, Richard L. and Richard M. Steers. Organizations: A Micro/Macro Approach. Glenview IL: Scott, Forseman and Company, 1986.

4. Department of the Air Force. Air Force Reliability and Maintainability Program Fact Sheet. Washington: Secretary of the Air Force, Office of Public Affairs, December 1985.

5. Department of the Air Force. Reliability and Maintainability Action Plan: R&M 2000. Washington: HQ USAF, 1 February 1985.

6. Department of the Air Force. USAF R&M Action Plan Development Team Final Report: Volume I. Washington: HQ USAF, 1 February 1985.

7. Department of the Air Force. USAF R&M 2000 Process (First Edition). Washington: HQ USAF, October 1987.

8. Dorris, John, Chief, C-17 Supportability Engineering. Personal interviews. Douglas Aircraft Company, Long Beach CA, 21 through 25 March 1988.

9. Douglas Aircraft Company. C-17 Engineering Organization Chart. Long Beach CA, 2 November 1987.

10. Douglas Aircraft Company. C-17 Program: Design Decision Documentation. Company Standard Practice. Long Beach CA, 2 October 1986.

11. Douglas Aircraft Company. C-17 Program: R&M Quality Teams. Company Standard Practice. Long Beach CA, 27 June 1986.

12. Douglas Aircraft Company. Memorandum of Design for R&M. Long Beach CA, 2 December 1985.

13. Douglas Aircraft Company. Memorandum of Top Contributions of the C-17 R&M Quality Teams. Long Beach CA, 28 August 1987.

14. Douglas Aircraft Company. R&M Quality Team Discovery/Impact List. Unpublished report. Long Beach CA, 1987.

15. Douglas Aircraft Company. Review and Comment Sheet/Design Action Request. DAC Form 25-2413. Long Beach CA, November 1986.

16. Douglas Aircraft Company. Review Council Meeting Minutes. Long Beach CA, 31 December 1986.

17. Emory, C. William. Business Research Methods (Third Edition). Homewood IL: Richard D. Irwin, Incorporated, 1985.

18. Garvin, David A. Comments broadcast on American Interests, The Blackwell Corporation, Public Broadcasting System, 16 July 1988.

19. "General O'Loughlin Legacy: AFLC's 'Return to Basics' Focuses on Weapon Systems," Skywrighter, 28: 1,9 (31 July 1987).

20. Goodell, Brig Gen Frank S. "R&M 2000: A Solution to a Management Problem," TIG Brief, 38: 10 (September/October 1986).

21. Guzzi, Maj James F. R&M Program Manager, C-17 Program Office. Personal interviews. Aeronautical Systems Division, Wright-Patterson AFB OH, 15 June 1987 through 31 July 1988.

22. -----. R&M Quality Team Concept, A New System Management Initiative. Wright-Patterson AFB OH: Aeronautical Systems Division, 1986.

23. Hayes, Robert H. Comments broadcast on American Interests, The Blackwell Corporation, Public Broadcasting System, 16 July 1988.

24. Hess, R. S., Director, Product System Engineering. Personal interview. Douglas Aircraft Company, Long Beach CA, 24 March 1988.

25. Hill, Lori. "C-17 Program First to Incorporate USAF Initiative," Frontlines C-17, 2: 1 (1987).

26. Juran, J. M. Quality Control Handbook (Second Edition). New York: McGraw-Hill Book Company, 1962.

27. Juran, J. M. and Frank M. Gryna, Jr. Quality Planning and Analysis (Second Edition). New York: McGraw-Hill Book Company, 1980.

28. Kerlinger, Fred N. Foundations of Behavioral Research (Second Edition). New York: Holt, Rinehart & Winston, 1973.

29. Lindley, John H., Chief, C-17 System Engineering. Personal interview. Douglas Aircraft Company, Long Beach CA, 21 and 24 March 1988.

30. "Log Quality Equals Combat Strength," Skywrighter, 29: 1-2 (29 January 1988).

31. Lowin, A. L. "Participative Decision Making; A Model, Literature Critique, and Prescriptions for Research," Organizational Behavior and Human Performance, 3: 68-106 (1968).

32. Lyu, Maj Kyu Yeol and 1Lt Arthur E. Roffey. The Quality Circles Organizational Intervention: An Attitudinal Outcome Study. MS thesis, AFIT/LSSR/19-83. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1983 (AD-A134506).

33. McClave, James T. and P. George Benson. Statistics for Business and Economics (Third Edition). San Francisco: Dellen Publishing Company, 1985.

34. Meredith, Jack R. The Management of Operations (Third Edition). New York: John Wiley & Sons, Incorporated, 1987.

35. Meyer, Gordon W. and Randall G. Stott. "Quality Circles: Panacea or Pandora's Box?," Organizational Dynamics, 15: 34-50 (Spring 1985).

36. Military Airlift Command. The Case For The C-17: The Operator's View. Scott AFB IL: HQ MAC, 1986.

37. Minchello, Capt James B. Participative Decision Making and Quality Circles: A Look at Their Relationship in Three U.S. Government Organizations. MS thesis, AFIT/GLM/LSB/85S-52. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1985 (AD-A161360).

38. Moore, Capt Robert L. and Capt Robert E. Stevens. Quality Circles: Determination of Significant Factors for Success and a General Model for Implementing a Quality Circle Process. MS thesis, AFIT/LSSR/21-81. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, June 1981 (AD-A103784).

39. Mullins, Gen James P. "Reliability: Key to Cost Reduction," Program Manager, 13: 12-16 (September/October 1984).

40. Nims, Donald, Staff Manager to Director of Military Programs, Integrated Logistics Systems. Telephone interview. Douglas Aircraft Company, Long Beach CA, 24 March 1988.

41. Pauly, Capt J. D. "Reliable and Maintainable C-17 Design Features," Airlift, 9: 4-7 (Spring 1987).

42. Russ, Lt Gen Robert D. "Fourth Wheel on the Acquisition Wagon," Air Force Magazine, 68: 122-125 (March 1985).

43. Scarborough, Richard. "C-17 Aircraft: Reliability and Maintainability Have Become Watchwords for the Airlifter," Military Logistics Forum: 55-56 (November/December 1986).

44. Siegele, D. H., Chief, C-17 Design Engineering. Personal interview. Douglas Aircraft Company, Long Beach CA, 21 and 24 March 1988.

45. Smith, Bruce A. "Douglas Stresses Reliability Early in C-17 Development," Aviation Week & Space Technology, 127: 61-62 (20 July 1987).

46. Steers, Richard M. et al. Managing Effective Organizations: An Introduction. Boston: Kent Publishing Company, 1985.

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In response to U.S. Air Force emphasis on improving weapon system reliability and maintainability (R&M), Major James F. Guzzi of the Aeronautical Systems Division's C-17 System Program Office located at Wright-Patterson Air Force Base, Ohio, developed a quality management initiative called the R&M Quality Team Concept. The purpose of the concept is to provide companies better management of R&M during the Full-Scale Engineering Development acquisition phase. Douglas Aircraft Company (DAC) agreed to implement the R&M Quality Team Concept during design of the C-17, the Air Force's next-generation transport aircraft.

This thesis examined the effect of the R&M Quality Team Concept as instituted by DAC on the quality management of the R&M process during C-17 design. Research assessed the concept's perceived impact on the following three areas: (1) communication on R&M issues, (2) R&M problem solving, and (3) specific C-17 design changes. Research instruments consisted of a survey administered to DAC employees and interviews with management at DAC's Long Beach, California, facility. Hypothesis testing using z and t-tests assisted in evaluating survey results.

The results of this study revealed overall employee support for the R&M Quality Team Concept. The concept provided a method of R&M management and problem solving not available in a traditional program organization, and a number of C-17 design changes resulted from concept application. Studying the R&M Quality Team Concept's use in other program organizations and its function in managing R&M during the transition from Full-Scale Development to Production is recommended.